CLAIMS

What is claimed is:

1. A process for preparing a silicon melt in a crucible for use in growing a single crystal silicon ingot by the Czochralski method, the process comprising:

a. forming a partially melted charge in the crucible, the partially melted charge comprising molten silicon and unmelted polycrystalline silicon, the molten silicon having an upper surface, the unmelted polycrystalline silicon comprising an exposed portion that is above the upper surface of the molten silicon;

b. rotating the crucible;

c. feeding polycrystalline silicon into the rotating crucible by intermittently delivering the fed polycrystalline silicon onto the exposed unmelted polycrystalline silicon, the intermittent delivery comprising a plurality of alternating on-periods and off-periods, wherein each on-period comprises flowing the fed polycrystalline silicon through a feed device that directs the flow of the fed polycrystalline silicon onto the unmelted polycrystalline silicon for an on-duration, and each off-period comprises interrupting the flow of the fed polycrystalline silicon for an off-duration; and

d. melting the unmelted polycrystalline silicon and the fed polycrystalline silicon to form the silicon melt.

2. A process for preparing a silicon melt in a crucible for use in growing a single crystal silicon ingot by the Czochralski method, the process comprising:

a. loading the crucible with polycrystalline silicon;

b. rotating the loaded crucible;

c. heating the loaded polycrystalline silicon to form molten silicon and unmelted polycrystalline silicon, the molten silicon comprising an upper surface, the unmelted polycrystalline silicon comprising an exposed portion that is above the upper surface of the molten silicon;

d. feeding polycrystalline silicon into the rotating crucible by intermittently delivering the fed polycrystalline silicon onto the exposed unmelted polycrystalline silicon, the intermittent delivery comprising a plurality of alternating on-periods and off-periods, wherein each on-period comprises flowing the fed polycrystalline silicon through a feed device that directs the flow of the fed polycrystalline silicon onto the unmelted polycrystalline silicon for an on-duration, and each off-period comprises interrupting the flow of the fed polycrystalline silicon for an off-duration; and

e. melting the loaded polycrystalline silicon and the fed polycrystalline silicon to form the silicon melt.

3. A process for preparing a silicon melt in a crucible for use in growing a single crystal silicon ingot by the Czochralski method, the process comprising:

a. loading the crucible with polycrystalline silicon, the crucible comprising an interior wall and having an inner diameter, *D*;

b. rotating the loaded crucible at a rate, *r*;

c. heating the loaded polycrystalline silicon to form molten silicon and unmelted polycrystalline silicon, the molten silicon comprising an upper surface, the unmelted polycrystalline silicon comprising an exposed portion that is above the upper surface of the molten silicon, the exposed unmelted polycrystalline having a center and a width, *d*, that corresponds to the longest distance between two points along the interface between the exposed unmelted polycrystalline silicon and the upper surface of the molten silicon;

d. feeding a polycrystalline silicon mass into the rotating crucible by intermittently delivering a portion of the polycrystalline silicon mass at a feed rate, F, onto the exposed unmelted polycrystalline thereby maintaining the width of the exposed unmelted polycrystalline silicon, d, the intermittent delivery comprising a plurality of alternating on-periods and off-periods, wherein each on-period comprises flowing polycrystalline silicon at a flow rate, f, for a duration, t_{on}, through a feed device that directs the polycrystalline silicon onto the exposed unmelted polycrystalline silicon, and wherein each off-period comprises interrupting the flow of polycrystalline silicon through the feed device for a duration, t_{off}; and

e. melting the loaded polycrystalline silicon and the fed polycrystalline silicon to form the silicon melt.

4. The process as set forth in claim 3 wherein the interface between the unmelted polycrystalline silicon and the upper surface of the molten silicon is approximately equidistant from the center of the unmelted polycrystalline silicon.

5. The process as set forth in claim 4 wherein the interface between unmelted polycrystalline silicon and the upper surface of the molten silicon is approximately equidistant from the interior wall of the crucible.

6. The process as set forth in claim 5 wherein the crucible is loaded with chunk polycrystalline silicon and the crucible is fed with granular polycrystalline silicon.

7. The process as set forth in claim 6 wherein the loaded chunk polycrystalline silicon comprises about 40% to about 65% by weight of the silicon melt.

8. The process as set forth in claim 6 wherein the loaded chunk polycrystalline silicon comprises about 50% to about 60% by weight of the silicon melt.

9. The process as set forth in claim 6 wherein *d* ranges from about 65% to about 85% of *D*.

10. The process as set forth in claim 6 wherein *d* is about 75% of *D*.

11. The process as set forth in claim 6 wherein *r* is at least about 1 rpm.

12. The process as set forth in claim 6 wherein *r* ranges from about 1 rpm to about 5 rpm.

13. The process as set forth in claim 6 wherein *r* ranges from about 2 rpm to about 3 rpm.

14. The process as set forth in claim 6 wherein *r* is about 2.1 rpm.

15. The process as set forth in claim 6 wherein *F* is at least about 1 kg/hr.

16. The process as set forth in claim 6 wherein *F* ranges from about 1.5 kg/hr to about 65 kg/hr.

17. The process as set forth in claim 6 wherein *F* ranges from about 5 kg/hr to about 30 kg/hr.

18. The process as set forth in claim 6 wherein F ranges from about 10 kg/hr to about 20 kg/hr.

19. The process as set forth in claim 6 wherein f is at least about 1 g/s.

20. The process as set forth in claim 6 wherein f ranges from about 5 g/s to about 35 g/s.

21. The process as set forth in claim 6 wherein f ranges from about 10 g/s to about 25 g/s.

22. The process as set forth in claim 6 wherein t_{on} is at least about 1 second.

23. The process as set forth in claim 6 wherein t_{on} ranges from about 2 seconds to about 10 seconds.

24. The process as set forth in claim 6 wherein t_{on} ranges from about 4 seconds to about 10 seconds.

25. The process as set forth in claim 6 wherein t_{on} is about 5 seconds.

26. The process as set forth in claim 6 wherein t_{off} is at least about 1 second.

27. The process as set forth in claim 6 wherein t_{off} is at least about 5 seconds.

28. The process as set forth in claim 6 wherein t_{off} ranges from about 10 seconds to about 30 seconds.

29. The process as set forth in claim 6 wherein t_{off} ranges from about 10 seconds to about 20 seconds.

30. The process as set forth in claim 6 wherein t_{off} ranges from about 10 seconds to about 15 seconds.

31. The process as set forth in claim 6 wherein t_{off} is about 12 seconds.

32. The process as set forth in claim 6 wherein the flow of the granular polycrystalline silicon is interrupted during the off-period using an angle of repose valve.

33. The process as set forth in claim 6 wherein the feed device directs the granular polycrystalline silicon onto a portion of the exposed unmelted polycrystalline.

34. The process as set forth in claim 33 wherein the feed device through which the granular polycrystalline silicon is flowed is a vertical-type feed tube that is positioned so that it is not directly above the center of the exposed unmelted polycrystalline silicon.

35. The process as set forth in claim 33 wherein the feed device through which the granular polycrystalline silicon is flowed is a spray-type feed tube.

36. The process as set forth in claim 33 wherein the portion of the exposed unmelted polycrystalline upon which the granular polycrystalline silicon is delivered is a wedge that extends radially outward from about the center to the interface between the unmelted polycrystalline silicon and the upper surface of the molten silicon.

37. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 180°.

38. The process as set forth in claim 36 wherein the wedge has a wedge angle that is less than about 180°.

39. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 120°.

40. The process as set forth in claim 36 wherein the wedge has a wedge angle that is less than about 120°.

41. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 90°.

42. The process as set forth in claim 36 wherein the wedge has a wedge angle that is less than about 90°.

43. The process as set forth in claim 36 wherein the wedge has a wedge angle that ranges from about 40° to about 72°.

44. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 72°.

45. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 60°.

46. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 51.4°.

47. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 45°.

48. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 40°.

49. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 36°.

50. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 30°.

51. The process as set forth in claim 36 wherein the wedge has a wedge angle that is about 27.7°.

52. The process as set forth in claim 36 wherein each wedge on the exposed unmelted polycrystalline silicon does not substantially overlap with the immediately preceding wedge.

53. The process as set forth in claim 52 wherein granular polycrystalline silicon is deposited on the entire exposed unmelted polycrystalline silicon prior to redepositing granular polycrystalline silicon on any wedge.

54. The process as set forth in claim 53 wherein each subsequent wedge is deposited adjacent to the immediately preceding wedge and within one rotation of the crucible after the immediately preceding wedge.

55. The process as set forth in claim 53 wherein each subsequent wedge is deposited adjacent to the immediately preceding wedge and following at least one rotation of the crucible after the immediately preceding wedge.

56. The process as set forth in claim 53 wherein each subsequent wedge is deposited nearly opposite from the immediately preceding wedge, and adjacent to the second-most recent wedge and within one rotation of the crucible after the second-most recent wedge.

57. The process as set forth in claim 53 wherein each subsequent wedge is deposited nearly opposite from the immediately preceding wedge, and adjacent to the second-most recent wedge and following at least one rotation of the crucible after the second-most recent wedge.

58. The process as set forth in claim 52 wherein granular polycrystalline silicon is redeposited on a wedge prior to the depositing granular polycrystalline silicon on the entire exposed unmelted polycrystalline silicon.

59. A process for preparing a silicon melt in a crucible from polycrystalline silicon for use in growing a single crystal silicon ingot by the Czochralski method, the process comprising:

a. loading the crucible with chunk polycrystalline silicon, the amount of the chunk polycrystalline silicon load being between about 40% to

about 65% by weight of the total amount of the polycrystalline silicon melted to form the silicon melt;

b. rotating the loaded crucible;

c. heating the loaded chunk polycrystalline silicon to form molten silicon and unmelted polycrystalline silicon, the molten silicon comprising an upper surface, the unmelted polycrystalline silicon comprising an exposed portion that is above the upper surface of the molten silicon, the exposed unmelted polycrystalline having a center and a width that corresponds to the longest distance between two points along the interface between the exposed unmelted polycrystalline silicon and the upper surface of the molten silicon, the interface between the unmelted polycrystalline silicon and the upper surface of the molten silicon being approximately equidistant from the center of the unmelted polycrystalline silicon;

d. feeding a granular polycrystalline mass into the rotating crucible by intermittently delivering a portion of the granular polycrystalline silicon mass onto the exposed unmelted polycrystalline silicon thereby maintaining the width of the exposed unmelted polycrystalline silicon, the intermittent delivery comprising a plurality of alternating on-periods and off-periods, wherein each on-period comprises flowing the granular polycrystalline silicon through a feed device that directs the granular polycrystalline silicon onto a wedge of the exposed unmelted polycrystalline silicon that does not substantially overlap with the immediately preceding wedge, and wherein each off-period comprises interrupting the flow of polycrystalline silicon through the feed device; and

e. melting the loaded polycrystalline silicon and the fed polycrystalline silicon to form the silicon melt.

60. A process for preparing a silicon melt in a crucible from polycrystalline silicon for use in growing a single crystal silicon ingot by the Czochralski method, the process comprising:

a. loading the crucible with chunk polycrystalline silicon, the amount of the chunk polycrystalline silicon load being between about 40% to about 65% by weight of the total amount of the polycrystalline silicon melted to form the silicon melt, the crucible comprising an interior wall and having an inner diameter, *D;*

b. rotating the loaded crucible at a rate, *r*, that ranges from about 1 rpm to about 5 rpm;

c. heating the loaded chunk polycrystalline silicon to form molten silicon and unmelted polycrystalline silicon, the molten silicon comprising an upper surface, the unmelted polycrystalline silicon comprising an exposed portion that is above the upper surface of the molten silicon, the exposed unmelted polycrystalline having a center and a width, *d*, that corresponds to the longest distance between two points along the interface between the exposed unmelted polycrystalline silicon and the upper surface of the molten silicon, the interface between the unmelted polycrystalline silicon and the upper surface of the molten silicon being approximately equidistant from the center of the unmelted polycrystalline silicon and approximately equidistance from the interior wall of the crucible;

d. feeding a granular polycrystalline mass into the rotating crucible by intermittently delivering a portion of the granular polycrystalline silicon mass onto the exposed unmelted polycrystalline silicon thereby maintaining the width of the exposed unmelted polycrystalline silicon, *d*, at about 65% to about 85% of the crucible diameter, *D*, the intermittent delivery comprising a plurality of alternating on-periods and off-periods, wherein each on-period comprises flowing the granular

polycrystalline silicon at a flow rate, f, of about 5 g/s to about 35 g/s for duration, t_{on}, of about 2 seconds to about 10 seconds through a feed device that directs the granular polycrystalline silicon onto a wedge of the exposed unmelted polycrystalline silicon wherein each wedge has a wedge angle of about 40° to about 72° and each wedge does not substantially overlap with the immediately preceding wedge, and wherein each off-period comprises interrupting the flow of polycrystalline silicon through the feed device for a duration, t_{off}, of at least about 5 seconds; and

e. melting the loaded polycrystalline silicon and the fed polycrystalline silicon to form the silicon melt.

61. The process as set forth in claim 60 wherein d is about 75% of D, r ranges from about 2 rpm to about 3 rpm, f ranges from about 10 g/s to 25 g/s, t_{on} ranges from about 4 seconds to about 10 seconds, and t_{off} ranges from about 10 seconds to about 30 seconds.

62. The process as set forth in claim 60 wherein granular polycrystalline silicon is deposited on the entire exposed unmelted polycrystalline silicon prior to redepositing granular polycrystalline on any wedge.

63. The process as set forth in claim 62 wherein each subsequent wedge is deposited adjacent to the immediately preceding wedge and within one rotation of the crucible after the immediately preceding wedge.

64. The process as set forth in claim 62 wherein each subsequent wedge is deposited adjacent to the immediately preceding wedge and following at least one rotation of the crucible after the immediately preceding wedge.

65. The process as set forth in claim 62 wherein each subsequent wedge is deposited nearly opposite from the immediately preceding wedge, and adjacent to the second-most recent wedge and within one rotation of the crucible after the second-most recent wedge.

66. The process as set forth in claim 62 wherein each subsequent wedge is deposited nearly opposite from the immediately preceding wedge, and adjacent to the second-most recent wedge and following at least one rotation of the crucible after the second-most recent wedge.

67. The process as set forth in claim 60 wherein granular polycrystalline silicon is redeposited on a wedge prior to the depositing granular polycrystalline silicon on the entire exposed unmelted polycrystalline silicon.

68. A process for preparing a silicon melt in a crucible for use in growing a single crystal silicon ingot by the Czochralski method, the process comprising:

a. rotating the crucible at a rate, *r*;

b. forming a depleted molten silicon charge in the rotating crucible, the depleted molten silicon charge having a weight, *w*, the crucible comprising an interior wall and having an inner diameter, *D*;

c. feeding polycrystalline silicon into the rotating crucible by delivering the polycrystalline silicon onto the depleted molten silicon charge to form a partial charge comprising molten silicon and unmelted polycrystalline silicon, the molten silicon comprising an upper surface, the unmelted polycrystalline silicon comprising an exposed portion that is above the surface of the molten silicon, the exposed unmelted polycrystalline silicon having a center and width, *d*, that corresponds to the longest distance between two points along the interface between the exposed unmelted polycrystalline silicon and upper surface of the molten silicon;

d. feeding polycrystalline into the rotating crucible by intermittently delivering polycrystalline silicon onto the exposed unmelted polycrystalline silicon thereby maintaining the width of the exposed unmelted polycrystalline silicon, *d*, the intermittent delivery comprising a plurality of alternating on-periods and off-periods, wherein each on-period comprises flowing polycrystalline silicon at a flow rate, *f*, for a duration, t_{on}, through a feed device that directs the polycrystalline silicon onto the exposed unmelted polycrystalline silicon, and wherein each off-period comprises interrupting the flow of polycrystalline silicon through the feed device for a duration, t_{off}; and

e. melting the unmelted polycrystalline silicon and the intermittently delivered polycrystalline silicon to form the silicon melt.

69. The process as set forth in claim 68 wherein *w* is about 15% to about 40% by weight of the silicon melt.

70. The process as set forth in claim 68 wherein *w* is about 20% to about 30% by weight of the silicon melt.

71. The process as set forth in claim 68 wherein the interface between the unmelted polycrystalline silicon and the upper surface of the molten silicon is approximately equidistant from the center of the unmelted polycrystalline silicon and approximately equidistant from the interior wall of the crucible.

72. The process as set forth in claim 71 wherein the crucible is fed with granular polycrystalline silicon.

73. The process as set forth in claim 72 wherein *d* ranges from about 65% to about 85% of *D*.

74. The process as set forth in claim 72 wherein *d* is about 75% of *D*.

75. The process as set forth in claim 73 wherein *r* ranges from about 1 rpm to about 5 rpm.

76. The process as set forth in claim 73 wherein *r* ranges from about 2 rpm to about 3 rpm.

77. The process as set forth in claim 75 wherein *f* ranges from about 5 g/s to about 35 g/s.

78. The process as set forth in claim 75 wherein *f* ranges from about 10 g/s to about 25 g/s.

79. The process as set forth in claim 77 wherein t_{on} ranges from about 2 seconds to about 10 seconds.

80. The process as set forth in claim 77 wherein t_{on} ranges from about 4 seconds to about 10 seconds.

81. The process as set forth in claim 79 wherein t_{off} is at least about 5 seconds.

82. The process as set forth in claim 79 wherein t_{off} ranges from about 10 seconds to about 30 seconds.

83. The process as set forth in claim 79 wherein t_{off} ranges from about 10 seconds to about 20 seconds.

84. The process as set forth in claim 79 wherein t_{off} ranges from about 10 seconds to about 15 seconds.

85. The process as set forth in claim 81 wherein the feed device directs the granular polycrystalline silicon onto a portion of the exposed unmelted polycrystalline.

86. The process as set forth in claim 85 wherein the portion of the exposed unmelted polycrystalline silicon upon which the granular polycrystalline silicon is delivered is a wedge that extends radially outward from about the center to the interface between the unmelted polycrystalline silicon and the upper surface of the molten silicon.

87. The process as set forth in claim 86 wherein the wedge has a wedge angle that is less than about 180°.

88. The process as set forth in claim 86 wherein the wedge has a wedge angle that ranges from about 40° to about 72°.

89. The process as set forth in claim 86 wherein the wedge has a wedge angle that is about 60°, or 51.4°, or 45°, or 40°, or 36°, or 30° or 27.7°.

90. The process as set forth in claim 86 wherein each wedge on the exposed unmelted polycrystalline silicon does not substantially overlap with the immediately preceding wedge.

91. The process as set forth in claim 90 wherein granular polycrystalline silicon is deposited on the entire exposed unmelted polycrystalline silicon prior to redepositing granular polycrystalline silicon on any wedge.

92. The process as set forth in claim 91 wherein each subsequent wedge is deposited adjacent to the immediately preceding wedge and within one rotation of the crucible after the immediately preceding wedge.

93. The process as set forth in claim 91 wherein each subsequent wedge is deposited adjacent to the immediately preceding wedge and following at least one rotation of the crucible after the immediately preceding wedge.

94. The process as set forth in claim 91 wherein each subsequent wedge is deposited nearly opposite from the immediately preceding wedge, and adjacent to the second-most recent wedge and within one rotation of the crucible after the second-most recent wedge.

95. The process as set forth in claim 91 wherein each subsequent wedge is deposited nearly opposite from the immediately preceding wedge, and adjacent to the second-most recent wedge and following at least one rotation of the crucible after the second-most recent wedge.

96. The process as set forth in claim 90 wherein granular polycrystalline silicon is redeposited on a wedge prior to the depositing granular polycrystalline silicon on the entire exposed unmelted polycrystalline silicon.